CVD Diamond for High Power and High Temperature Electronics

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Polycrystalline Diamond films produced by Microwave Plasma Enhanced Chemical Vapor Deposition (MWCVD) were investigated for high power and high temperature electronic applications. The diamond films were deposited on tungsten substrates and on silicon substrates coated with metal electrodes. Due to the difference in the thermal expansion coefficients of diamond and tungsten, cohesive freestanding diamond films ranging from 10µm and 150µm thick were obtained as the diamond films parted from the tungsten substrates as the samples cooled after deposition. Test devices were fabricated on both freestanding diamond and diamond on silicon substrates. Dielectric characterization was performed as a function of frequency and temperature. Voltage breakdown, I-V characteristics, insulation resistance, resistivity and thermal conductivity measurements were also performed. The film quality was assessed using SEM, XRC, Raman spectroscopy and electrical characterization.

At room temperature, high quality CVD diamond films had dielectric constants ranging from 5 to 7 and loss tangents less than 0.001 over the frequency range of 100 Hz to 10^6 Hz. These values were very steady over the entire frequency range. Variations in the low frequency range ($\nu < 500$ Hz) are artifacts resulting from the LCR meter's reduced sensitivity in that range.

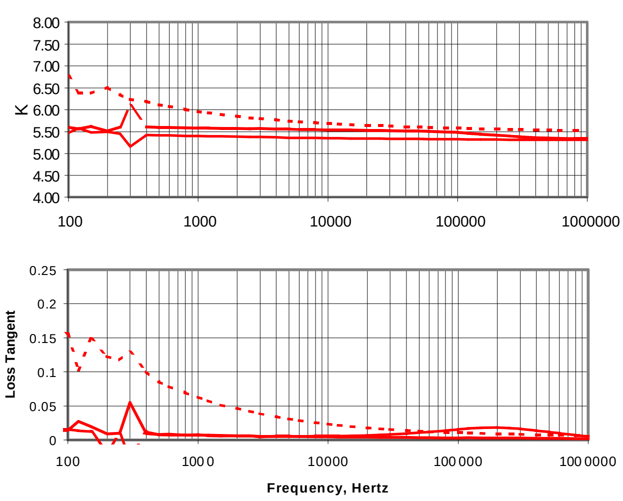

Figure 1 shows (a) the dielectric constant and (b) the loss tangent as a function of frequency. (Solid line = room temp., dotted lines= 300°C and dashed lines = cooled down to room temp.)

The temperature behavior of the dielectric constants and loss tangents were examined by cycling the temperature in 50°C increments up to 300°C and down to room temperature, and by maintaining the temperature at 300°C for 2 hours. The tests were performed on a hot plate in air, and heating and cooling rates were not held constant.

The dielectric constant of high quality CVD diamond varied by less than 10% with temperature cycling to 300°C. However, considerable variation in the dielectric loss was observed as the temperature was cycled. The dielectric losses remained very low and stable up to 150°C (less than 0.01). By 200°C, the dielectric loss had increased to 5X its room temperature value and by 300°C the dielectric loss was 0.06.

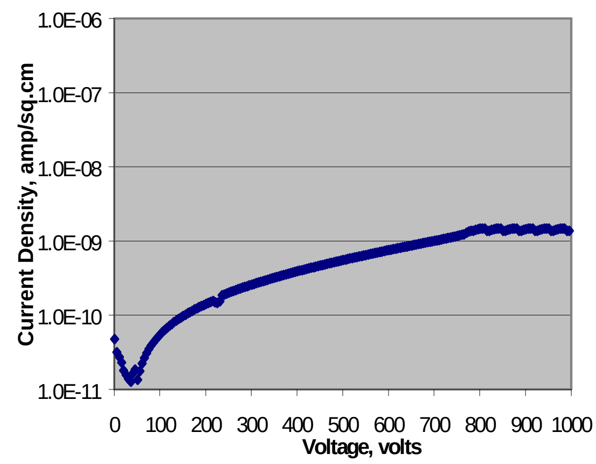

Figure 2 Current-voltage characteristics of CVD diamond

O. Sanchez-Garrido et al. attribute strong low frequency dispersion to the presence and size of grain boundaries in the film and to mobility of charge carriers, namely non-diamond carbon.[2] Thermal activation of charge carriers and relaxation at the grain boundaries would increase as the temperature increases, resulting in greater losses at higher temperatures. However, increased contact resistance at higher temperatures would also result in higher losses especially at lower frequencies. Increased losses result either from grain boundary relaxation and/or thermal activation of nondiamond carbon species in the diamond film, or from metal contact/interface effects, or a combination of both.

Conventional electrical breakdown does not typically occur in CVD diamond that is several microns thick in the 1000 V test range. However, dielectrics with high leakage currents make inferior capacitors. Hence, effective breakdown was defined as a leakage current over $1x10^{-6}$ A/cm^2. The current density of high quality CVD diamond was $5x10^{-11}$ A/cm^2 below 100 V and gradually increased to $1x10^{-9}$ A/cm^2 when 1000 V was applied. The resistivities of high quality CVD diamond were on the order of 10^{14} ohm-cm and breakdown voltages approached that of natural diamond (less than an order of magnitude difference). Applications of CVD diamond in high temperature and high power passive devices and switches will be presented.

1. Field, J.E. ed., The Properties of Diamond, (Academic Press, London, 1979).
2. O. Sanchez-Garrido, C. Gomez-Aleixandre, J. Sanchez Olias, J.M. Albella, M. Hernandez-Velez, F. Fernandez Gutierrez, J. Mater. Sci.: Materials in Electronics 7 (1996) 297-303.
3. S. Heidger, S. Fries-Carr, J. Weimer, B. Jordan & R.Wu, Material Research Society 1998 Spring Meeting, San Francisco, CA, April 13-17, 1998.